

# Modelling Back-to-Back Converter with Average Model in Wind Power System using DFIG

Anisa Harumwidiah<sup>1</sup>, Mochamad Ashari<sup>1</sup>, and Dedet C. Riawan<sup>1</sup>

**Abstract**—The total energy consumption in this year increase significantly. Most of energy that used come from fossil fuel. The use of fossil fuel can cause a lot of pollution and the amount of them is decreased. Therefore, many countries developing renewable energy system. One of renewable energy system is wind power using Doubly Fed Induction Generator (DFIG). DFIG supplies AC current from the stator winding that are connected directly to the grid and rotor winding DFIG are also connected to the grid through power electronic converter. The type of this converter is back-to-back converter. In general, this converter used switching model. However, this model produce a slow simulation and high ripple. To solve this problem DFIG with average model in back-to-back converter is studied in this research. This design operated by controlling the rotor speed DFIG to produce maximum power and preserve the value of DC link voltage remains constant.

**Keywords**— DFIG, back-to-back converter, average model.

## I. INTRODUCTION

According to 2011 data, electrification ratio in Indonesia is around 71%. If small power plant that use oil as energy source is built in remote area, electric price will become very expensive because the high price of fuel distribution. Therefore, development of power plant with renewable energy source must be started.

One example of renewable energy source is wind power. This energy source has advantages such as environmental friendly and available in abundant amount in nature. One way to convert wind energy into electrical energy is using induction generator.

Induction generator has advantages which are cheaper and stronger construction. Induction generator consist of Doubly Fed Induction generator (DFIG) and Self Excited Induction Generator (SEIG).

DFIG has converter that located between rotor and grid. Therefore in only need about 30% of machine power maximum [1,2]. With a right control method, variable speed operation on the generator can be done. As a result, electric power can be generated both from stator and rotor to grid [3]. Controlling of induction generator is used to generate maximum power from wind turbine at varying wind speed.

DFIG that used AC-AC converter in its rotor circuit (Scherbius drive) has become a control standard in high power application that involving speed limiter for a long time. Vector-control technique has been widely used to control rotor excitation and torque independently [4]. Most of Scherbius DFIG system use either of naturally commutated DC-link converter [5] or cycloconverter [6]. The use DC-link converter has disadvantages which are high cost DC link valve and need extra commutation to operation at synchronous speed resulting bad performance at low speed. Problem of synchronous speed can be solved using cycloconverter. The

disadvantage of cycloconverter is absorbing harmonic current from supply side. Moreover, the system with cycloconverter need transformer to adjust voltage with grid system. These disadvantages can be solved using two voltage source current control inverter that connected back-to-back between rotor and the grid. The scheme of back-to-back converter in wind power generation system had proposed in [7, 8].

Common method that used to modelling back-to-back converter is hard switching model. The disadvantages of this model are not considering resonance effect and transition interval. This disadvantages can be solved using average model method that considering resonance effect and transition interval [9].

In this research average model method that proposed in [10] is used. The advantages of this model are more detailed modelling process and more comprehensive model. This method is focused in characteristic of the model and its application on modular simulation and non linear load. This model fulfill the requirement as follows:

- Keeping all non switching equipment and connection with model.
- Allowing inductor current, capacitor voltage and other variable can be measured directly in the model.
- No additional boundary except Kirchhoff's Current Law (KCL) and Kirchhoff's Voltage Law (KVL).
- Not limited to certain load type or load connection type. With modification due to real load, this model will be suitable for all load type and load connection that include non-linear load.

The method from [10] is applied in back-to-back converter in DFIG system. This proposed system is expected to generate simple but real DFIG system simulation.

## II. METHOD

In this section, the modelling of whole system, wind turbine, DFIG and back-to-back converter are presented.

### A. Modelling of whole system

This system consist of wind turbine, wound rotor induction machine, proposed back-to-back converter

<sup>1</sup>Anisa Harumwidiah, Mochamad Ashari, and Dedet C. Riawan are with Departement of Electrical Engineering, Faculty of Industrial Technology, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia. E-mail: [aharwid@gmail.com](mailto:aharwid@gmail.com); [ashari@ee.its.ac.id](mailto:ashari@ee.its.ac.id); [dedet@ee.its.ac.id](mailto:dedet@ee.its.ac.id).

with its controller circuit in doubly fed wind power generation and grid. The model of whole system is shown in Figure 1.

with:

- GB = Gear box  
 $P^*$  = Generator maximum reference power  
 $P_{act}$  = Generator actual power  
 $V_{dc}^*$  = DC-link capacitor reference voltage  
 $V_{dc}$  = DC-link capacitor actual voltage

The total rating of the wind power system is 9 MW. It is arranged from 6 wind turbine generator with each capacity of 1.5 MW.

### B. Modelling of Wind Turbine

The type of wind turbine that used in this research is horizontal axis. The basic equation of this model is:

$$P_\omega = \frac{1}{2} \rho C_p(\lambda, \beta) A v^3 \quad (1)$$

with:

- $P_\omega$  = Mechanic power (watt)  
 $P$  = Air density (1.22 kg/m<sup>3</sup>)  
 $A$  = Blade wide (m)  
 $v$  = Wind speed (m/s)  
 $C_p$  = Power coefficient

Equation of turbine torque is:

$$T_\omega = \frac{P_\omega}{\omega_r} \quad (2)$$

with:

- $\omega_r$  = rotor angular speed (rad/s)

Equation of tip speed ratio is:

$$\lambda = \frac{\omega_r r}{v} \quad (3)$$

with:

- $r$  = blade diameter

### C. Modelling of DFIG

DFIG is used to generate electrical energy by converting mechanical energy produced by wind turbine. DFIG consist of induction machine that work as generator. DFIG generate electric power through both of stator and rotor windings. Stator winding is directly connected to the grid. Rotor winding is connected to the grid through back-to-back converter and slip ring.

The turbine mechanical power and stator electrical power are determined by:

$$P_m = T_m \omega_r \quad (4)$$

$$P_s = T_{em} \omega_s \quad (5)$$

If losses is neglected, the equation become:

$$J \frac{d\omega_r}{dt} = T_m - T_{em} \quad (6)$$

When the rotor speed reach steady state speed,  $T_m = T_{em}$  and  $P_m = P_s + P_r$ , and the rotor electric power become:

$$P_r = P_m - P_s \quad (7)$$

$$P_r = -T_m \left( \frac{\omega_s - \omega_r}{\omega_s} \right) \omega_s \quad (8)$$

By substitute equation (5) to equation (8), the equation become:

$$P_r = -s P_s \quad (9)$$

$$s = \frac{(\omega_s - \omega_r)}{\omega_s} \quad (10)$$

Where:

- $P_m$  = Turbine mechanic power (watt)  
 $P_s$  = Stator electric power (watt)

- $P_r$  = Rotor electric power (watt)  
 $T_m$  = Turbine mechanic torque (Nm)  
 $T_{em}$  = Stator electric torque (Nm)  
 $\omega_r$  = Rotor angular speed (rad/s)  
 $\omega_s$  = Synchronous speed (rad/s)  
 $J$  = Turbine inertia constant (kgm<sup>2</sup>)  
 $s$  = slip

If induction machine work as generator,  $T_m$  will be positive and stator angular speed will be constant when grid frequency is constant. Based on (9), the power generating by rotor is smaller than power generating by stator. Power generating by rotor depend on slip value. If slip is negative then  $P_r$  will be positive and  $\omega_r$  higher than  $\omega_s$ . If slip is positive then  $P_r$  will be negative and  $\omega_r$  lower than  $\omega_s$ .

When slip is negative, rotor will supply power to DC bus causing rise in capacitor voltage. When slip is positive, rotor will absorb power from capacitor causing decrease in capacitor voltage. Therefore, converter is needed to increase or decrease DC bus voltage causing constant voltage.

### D. Average Model of Back-to-Back Converter

Generally, back-to-back converter is modelled using detailed model that use switching device in simulation. When this converter is connected to a complex circuit, especially system with high frequency switching, the time that needed to run the simulation will be very long. It makes the simulation become inflexible.

Concerning the situation, average model of back-to-back converter is proposed to generate flexible simulation for many different types of condition. Average model is faster than detailed model in simulation because it is not performing switching operation.

The basic concepts to build average model of back-to-back converter are:

1. Basic equation to build the average model are kirchoff current law and kirchoff voltage law.
2. The average model can be used in all load connection.
3. Average model of back-to-back converter consists of rotor side converter and grid side converter. Both converter has identical average model. The difference is only their controller.

Schema diagram of back-to-back converter average model is shown in Figure. 2. Each converter consists of two controlled voltage source. Voltage value of each controlled voltage source is determined by controller block. The voltage value of both grid side converter and rotor side converter are determined by:

$$V_{abc-ctrl} = V_{a-ctrl} + V_{b-ctrl} + V_{c-ctrl} \quad (11)$$

$$V_{ab-ctrl} = V_{a-ctrl} - V_{b-ctrl} \quad (12)$$

$$V_{bc-ctrl} = V_{b-ctrl} - V_{c-ctrl} \quad (13)$$

$$V_{ab-avg} = \frac{V_{ab-ctrl} \times V_{DC}}{2} \quad (14)$$

$$-V_{DC} < V_{ab-avg} < V_{DC} \quad (15)$$

$$V_{bc-avg} = \frac{V_{bc-ctrl} \times V_{DC}}{2} \quad (16)$$

$$-V_{DC} < V_{bc-avg} < V_{DC} \quad (17)$$

DC-link voltage is determined by

$$V_{DC} = \frac{I_{DC-grid} - I_{DC-rotor}}{C_{DC-link}} \quad (18)$$

### E. Controller Circuit of Back-to-Back Converter

Controller circuit of back-to-back converter consist of grid side controller and rotor side controller. Rotor side controller has function to make wind turbine generator output voltage to be same with grid voltage. Grid side controller has function to maintain DC-link voltage. The configuration of grid side controller is shown in Figure. 3. The configuration of rotor side controller is shown in Figure. 4.

## III. RESULT AND DISCUSSION

In this research, average modelling of back-to-back converter in wind power system is proposed. This converter is applied to control the power flow between rotor of DFIG and grid. To validate the proposed method, the results of the system with back-to-back average model is compared with the result of the similar system except the back-to-back converter is modelling with detailed model. The validation is running through computer simulation. The total simulation time 0.9 seconds. The change of grid voltage is given to both system. The initial voltage is 1 p.u. and it is changed to 0.5 p.u. at 0.3 seconds.

The result of the system with average model are shown in figure 5-8. Figure. 5 shows the generator phase A output voltage. The generator output voltage can follow the grid voltage. When the grid voltage is 1 p.u., the output generator voltage is also 1 p.u. When the grid voltage is changed to 0.5 p.u., the generator voltage is also 0.5 p.u. Figure. 6 shows the generator phase A output current. When the grid voltage down, the generator current is increase a bit. Figure. 7 shows the DC-link voltage. It can be seen that DC-link voltage can be maintained at 1150 V when the grid voltage is changed. It means that the rotor side controller can work well. Figure. 8 shows the generator output power. When the grid voltage is at its rating which is 1 p.u., the generator output power is also at its rating which is 9 MW. When the grid voltage goes down, the generator output power is also goes down and become around 55 MW. The result also shows that the output voltage, output current and DC-link voltage signals are smooth and almost without ripple.

The results of system with detailed model are shown in figure 9-12. Figure. 9 shows the generator phase A output voltage, Figure. 10 shows the generator phase A output current, Figure. 11 shows the DC-link voltage while Figure. 12 shows the generator output power. There is almost no difference between their response speed concerning change of grid voltage, compared with average model. The output current is also shows low ripple and almost no different with the output current of system with average model. However, the results of output voltage and DC-link voltage are show significant difference than system with average model. The output voltage and DC-link voltage signals show big ripple. Although this results are closer to the results in real system, the presence of ripple is not necessary for many kind of analysis through computer simulation

except for harmonic analysis. The results of system with average model is well enough to represent the condition of real system in many types of analysis through computer simulation.

Another difference between those two simulation method is the total time needed to finish the simulation. Both of those methods are simulated for 0.9 seconds. The system with detailed model needs 52.936 seconds to finish the simulation while the system with average model is only needs 9.786 seconds. This time difference is very useful, especially if the total simulation time is way longer than 0.9 seconds

## IV. CONCLUSION

Average model of back-to-back converter in wind turbine power system is proposed in this paper. The objective is to generate a more flexible simulation method than detailed model. The time needed must be faster and the presence of ripple is not needed. The simulation results show that the accuracy and response of both system is not different. The main differences are the output voltage signal and DC-link voltage signal. The results of simulation with detailed model show big ripple while the results from average model show small ripple. The time needed to finish the simulation is also faster in system with average model. The system with average model only needs 9.786 seconds to finish the simulation while the system with detailed model needs 52.936 seconds. It can be concluded that average model of back-to-back converter in wind power system is better to be used in computer analysis than detailed model because the average model is faster to finish and not showing unnecessary ripple.

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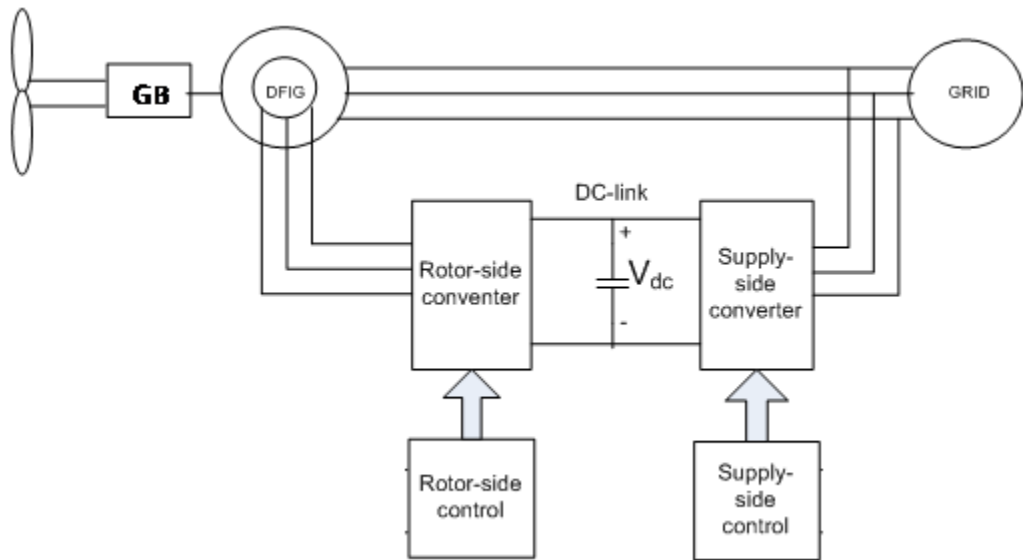


Figure 1. The Model of Whole System

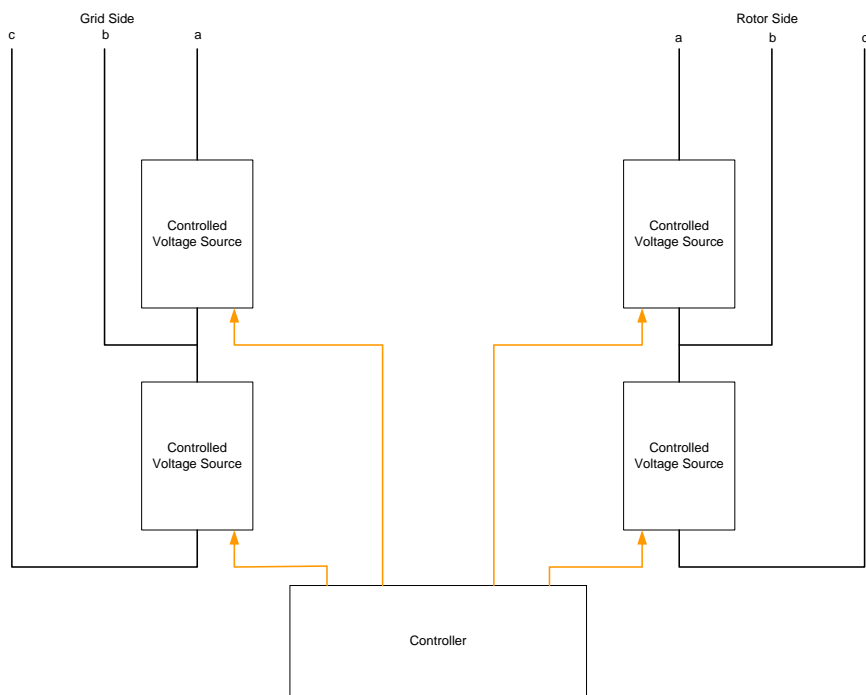


Figure 2. Average Model of Back-to-Back Converter

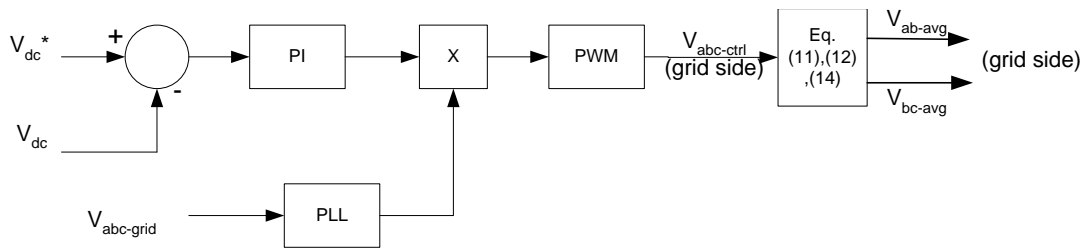


Figure 3. Grid Side Converter Controller

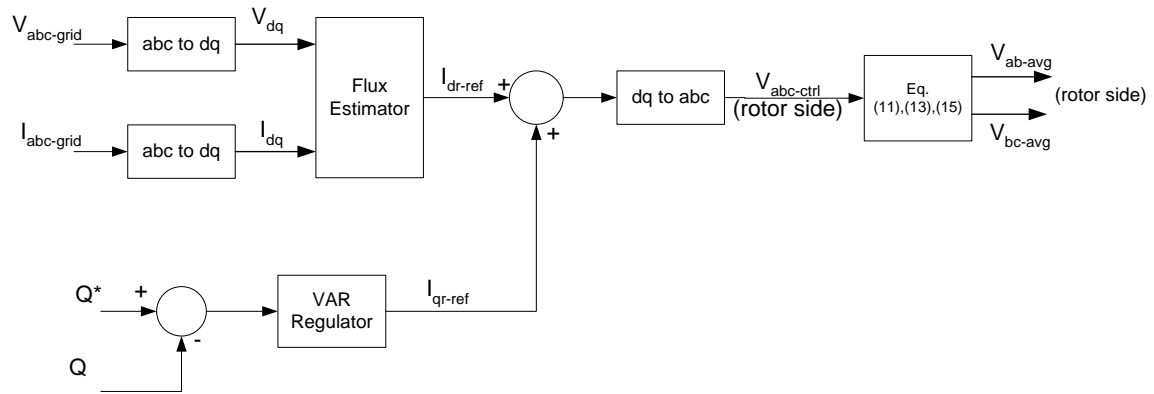


Figure 4. Rotor Side Converter Controller

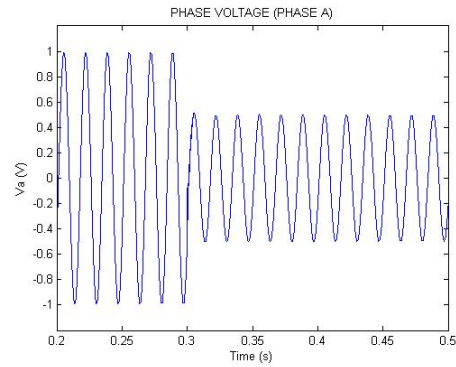


Figure 5. Output Voltage of System with Average Model

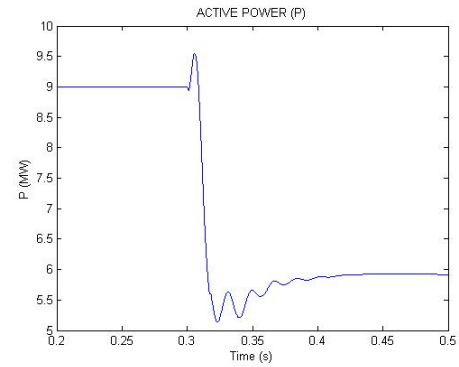


Figure 8. Output Power of System with Average Model

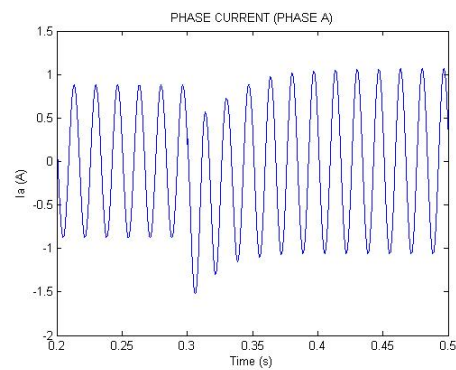


Figure 6. Output Current of System with Average Model

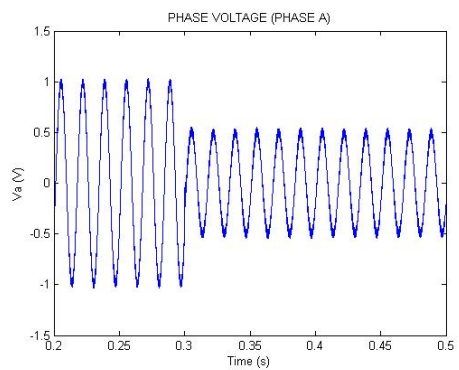


Figure 9. Output Voltage of System with Detailed Model

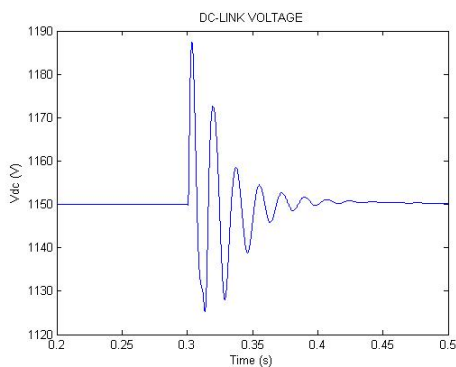


Figure 7. DC-Link Voltage of System with Average Model

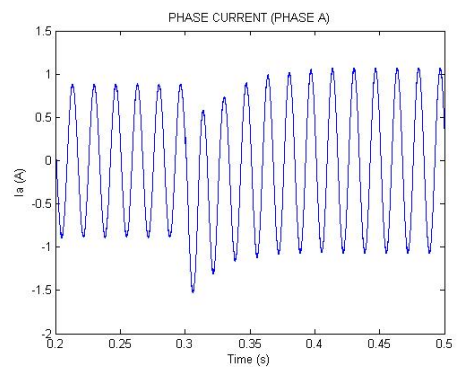


Figure 10. Output Current of System with Detailed Model

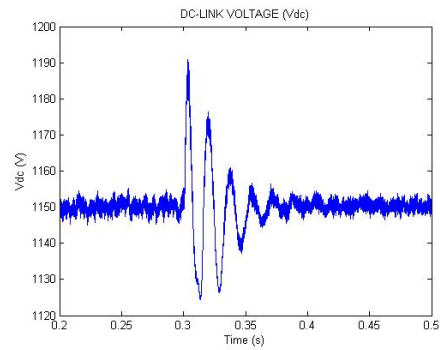


Figure 11. DC-Link Voltage of System with Detailed Model

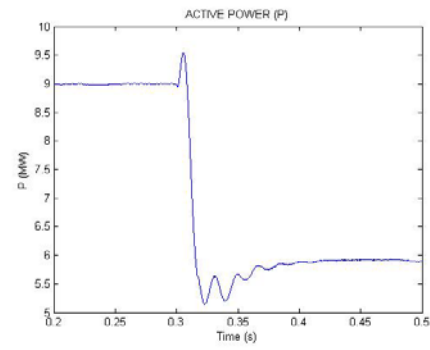


Figure 12. Output Power of System with Detailed Model